Resistance spot welding plays a critical role in the manufacture dissimilar material industry. However, there are differences in mechanical properties between mild steel and satinless steel so as to reduce the quality of welded joints. In order for differences in mechanical properties to be corrected, surface roughness was treated. The aim of this study was to optimize the welding parameters of DRSW with surface roughness by analysis using the Taguchi and Anova Methods. In this study discusses about investigates the Resistance spot welding parameters on weld geometry, mechanical properties, and SEM EDS on dissimilar materials of mild steel and stainless steel. The material thickness of the mild steel and stainless steel are 1 mm, respectively. The process parameters of the resistance spot welding joint used, example; surface roughness, current, welding time, and electrode force. Quality welding joint test results include weld geometry, mechanical properties, and SEM EDS. Weld geometry testing to determine the weld nugget profile. The mechanical properties test was shear tensile test, while the SEM EDS included macrostruture and microstructure observations. The results showed the highest nugget diameter 6.65 mm highest shear tensile strength 7.66 kN. The most influential parameter is current by 75.08 %, then surface roughness by 12.35 %. The highest tensile strength has fewer defects. Surface roughness treatment before welding is very good to make welding quality joints between mild steel and quality stainless steel increase. Surface roughness treatment was very good to be included when making welding procedures for welding engineers for welding processes resistance spot welding dissimilar mild steel with stainless steel

Keywords: resistance spot welding, dissimilar material, mild steel, stainless steel, surface roughness treatment

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OPTIMIZATION OF RESISTANCE SPOT WELDING WITH SURFACE ROUGHNESS DISSIMILAR MILD STEEL WITH STAINLESS STEEL

Ariyanto
Coresponding author
Doctor of Mechanical Engineering, Lecturer,
Head of Welding Workshop*
E-mail:ariyanto@atim.ac.id

Muhammad Setiawan Sukardin
Doctor of Mechanical Engineering, Lecturer,
Head of Welding Workshop*

Ilyas Renreng
Professor**

Hairul Arsyad
Doctor**

Muhammad Syahid
Doctor**

Muhammad Alwi
Doctor

Department of Mechanical Engineering
Stitek Dharma Yadi Makassar
Sukaria str., 1, Makassar, South Sulawesi, Indonesia, 90231

*Department of Manufacturing Agro Industrial Engineering
Politeknik ATI Makassar
Sunu str., 220, Makassar, Indonesia, 90211

**Department of Mechanical Engineering
Hasanuddin University
Malino str., 6, Gowa, South Sulawesi, Indonesia, 92171

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1. Introduction

Resistance spot welding is a welding method that is very widely used in the automotive, electronics, and other manufacturing industries. This is used to assemble thin sheets of metal in the automotive industry [1], car bodies, frames, doors, and tailgates [2]. This technique involves heating two sheets of metal to the melting point using a high electric current and strong pressure. After that, the two metal sheets are pressed together to form a welded joint.

In the automotive industry, using dissimilar materials on welded joints is very common [3]. For example, at the joints between the vehicle body and exterior components such as doors and hoods, it is common to use mild steel that is different from galvanized coatings on the surface. Such a connection between dissimilar materials AISI-1008 steel and aluminium-1100 alloy [4], dissimilar welding of high-entropy alloy to Inconel 718 superalloy [5], dissimilar joint of MS and ASS 304 sheets [6], dissimilar mild steel and stainless steel metal sheets [7], different nitinol and stainless steel wire [8].

However, these joints between different materials often experience problems such as defects, cracks, and joint failures due to differences in properties between dissimilar metals, thus degrading the quality of welded joints.

There are a number of reasons why it is necessary to conduct scientific research on the optimization of resistance spot welding with surface roughness dissimilar mild steel with stainless steel in modern conditions: Dissimilar metal welds are increasingly being used in modern manufacturing.

This is due to the need to combine the different properties of different metals to create products that are both strong and lightweight [9]. For example, dissimilar metal welds are used in the automotive industry to join aluminum and steel, and in the aerospace industry to join titanium and aluminum. Resistance spot welding is a versatile and efficient welding process. It is widely used in the automotive, aerospace, and electronics industries. However, it is important to optimize the welding parameters to ensure the quality of the welds, especially for dissimilar metal welds. Surface roughness can have a significant impact on the quality of resistance spot welds [10]. This is because surface roughness can affect the contact resistance between the electrodes and the workpieces. In addition, surface roughness can create stress concentrations in the weld nugget, which can lead to failure. There is a lack of understanding of the relationship between surface roughness and the resistance spot welding of dissimilar metals. This is because most research on resistance spot welding has focused on the welding of similar metals.

The results of these studies could be used in practice: a car manufacturer could use the results of these studies to develop a new resistance spot welding machine that is specifically designed for welding aluminum and steel panels together. This would allow the manufacturer to produce stronger and lighter cars, which would improve fuel efficiency and reduce emissions [11]. An aerospace company could use the results of these studies to develop a new welding procedure for joining titanium and aluminum components in aircraft [12]. This would allow the company to produce aircraft that are stronger and lighter, which would improve performance and reduce operating costs. An electronics company could use the results of these studies to develop a new quality control method for inspecting dissimilar metal welds in electronic devices. This would allow the company to ensure that the welds meet the required standards, which would improve product quality and reliability. The increasing use of dissimilar metal welds in modern manufacturing. Dissimilar metal welds are used in a wide range of industries, including automotive, aerospace, electronics, and construction. For example, dissimilar metal welds are used to join aluminum and steel in cars, titanium and aluminum in aircraft, and copper and aluminum in electronic devices.

The importance of weld quality and reliability. Dissimilar metal welds are often used in critical applications where weld quality and reliability are essential. For example, dissimilar metal welds are used to join structural components in aircraft and cars, and to connect electrical components in electronic devices. The challenges of welding dissimilar metals with different surface roughnesses. The surface roughness of the workpieces can have a significant impact on the quality and reliability of dissimilar metal welds. This is because surface roughness can affect the contact resistance between the electrodes and the workpieces, as well as the formation of the weld nugget. Studies that are devoted to the optimization of resistance spot welding with surface roughness dissimilar mild steel with stainless steel are scientifically relevant. This is because they can help us to better understand the relationship between surface roughness and the resistance spot welding of dissimilar metals. This knowledge can then be used to develop new welding procedures and machines that can produce high-quality welds consistently and reliably. In addition, studies on this topic can help us to identify the optimal welding parameters for different surface roughnesses and material combinations. This information can then be used to develop new quality control methods for inspecting dissimilar metal welds to ensure that they meet the required standards. Overall, studies on the optimization of resistance spot welding with surface roughness dissimilar mild steel with stainless steel have the potential to improve the quality, reliability, and cost-effectiveness of dissimilar metal welding. This could lead to a number of benefits for modern manufacturing.

To solve this problem in order to improve quality, several researchers have made efforts to improve quality, including: according to researchers [13] conducting of ice by ultrasonic immersion method with the intensity and amplitude of the resulting defective wave reaction and its effect on yield. Next, in other research [14] using the potentiodynamic polarization test in a 3.5 % NaCl environment, then measured the potential of base metal holes, heat-affected zones (HAZ) and fusion zones. In research [6] investigate the effect of weld parameters such as weld time, weld current, weld stress on weld strength. A new empirical relationship is established using factor regression and ANOVA to validate these results. They characterized the strength of the soldering chips, the microstructure, the microhardness and the behavior of the parameters on the responses.

In paper [15] develop a mathematical model using a regression analysis that shows the relationship of certain welding parameters to weld strength. In paper [16] reduced the formation of fragile intermetallic compounds using short welding times and a chemical composition that differs from the inserted element. Research results [1] assessing the effects of welding parameters on the overall quality of nuggets will be very important to resolve these problems.

When welding dissimilar metals with RSW, it is important to consider the difference in surface roughness between the two metals. A rougher surface will have a higher resistance, which will generate more heat during welding. This can lead to overheating and distortion of the weld nugget.

To optimize the RSW process for dissimilar metals with different surface roughnesses, it is important to control the welding parameters. The welding current, time, and electrode force should be adjusted to ensure that the weld nugget is properly formed without overheating the workpieces.

One way to optimize the RSW process for dissimilar metals with different surface roughnesses is to use a pulsed welding current. This involves applying a series of short pulses of current to the workpieces. Pulsed welding can help to reduce the amount of heat generated during welding, which can lead to better weld quality.

2. Literature review and problem statement

The paper [17] presents the results of the AA5754/Ti6Al4V dissimilar connection study, with resistance spot welding. Resistance spot welding shows the holding time affects the void appearing in the middle of the nugget. The presence of defects, significantly reduces the strength of the joint. Increased holding time, successfully eliminating defects and increasing the strength of welded joints. Furthermore, researchers [18] examined variations in electrode pressure. Found that as the electrode force increased, the crack size decreased. The least amount of cracking at 5 kN electrode force and 400 ms welding time. Optimization of resistance spot welding is important things done to make the welding process efficient, fast and produce high quality joints. Today, the industry is looking for high quality welded joints [19]. To optimize welding parameters, there are several parameters, including: the diameter of the weld nugget, which is evaluated by the peel test according to EN ISO 10440, this is also done in research [20], It can also be by testing the strength of the shear pull. This has been done by researchers in paper [21] One of the tests they did was shear tensile strength. can also be tested with macro structures, namely scanning electron microscope (SEM) testing. This has also been done by researchers in paper [22]. In addition, resistance spot welding is also effective for welding dissimilar materials. In research [22] connecting dissimilar mild steel with stainless steel using resistance spot welding.

Dissimilar joints as has been done by researchers by welding connections such as Al5052/CFRP [23], others examined the welding of dissimilar joints 304 austenitic stainless steel/AZ31B Mg by researchers [24], there are also researchers who perform resistance spot welding for TWIP/martensitic steel dissimilar materials [25], DP600/AISI304 dissimilar joint resistance welding has also been performed by researchers [26]. And finally, resistance spot welding of dissimilar metal/carbon fibre joints has been carried out by researchers [27].

The reason for this is the presence of differences in mechanical properties and the presence of differences in the structure of the joint surface. Welding these two materials together can be challenging due to their different compositions and properties. Mild steel is a low-carbon steel with relatively low strength and good ductility [28]. It is often chosen for its affordability and ease of fabrication [29]. On the other hand, stainless steel is an alloy of steel with a higher chromium content, which provides excellent corrosion resistance. The quality of the joints formed in dissimilar resistance spot welding (DRSW) can be challenging to achieve due to the differences in materials' properties and thermal conductivities. DRSW involves joining two or more different materials [30], which can lead to issues like intermetallic formation, thermal gradients, and weld nugget size variations. Dissimilar welding poses several challenges due to the disparities in thermal conductivity, melting points, and other properties of the materials involved. These differences can lead to issues such as the formation of brittle intermetallic compounds, the results showed that the treatment was able to eliminate brittle intermetallic compounds [31], In dissimilar joints there are differences in tensile strength, so the right welding method must be found [32], and In dissimilar joints there is a risk of defects contained, the results of the study show that in the area there are many defects. To achieve high-quality welds in dissimilar materials, it is crucial to carefully select welding parameters [33], optimize the process, and consider appropriate joint design and pre/post-weld heat treatments.

The way to overcome these difficulties can be by surface roughness treatment of the area to be joined. This approach has been used in similar materials, namely stainles steel, the effect of roughness has been tested. The results show that there is an influence of roughness on shear tensile strength [10]. However, there has been no research on how the effect of surface roughness on the strength of mild steel dissimilar joints with stainless steel. The existing literature highlights the influence of material combinations, welding parameters [34], intermetallic compound formation, surface contamination, and HAZ effects on surface roughness.

To optimize the RSW process for dissimilar metals with different surface roughnesses, it is important to control the welding parameters. The welding current, time, and electrode force should be adjusted to ensure that the weld nugget is properly formed without overheating the workpieces.

One way to optimize the RSW process for dissimilar metals with different surface roughnesses is to use a pulsed welding current. This involves applying a series of short pulses of current to the workpieces. Pulsed welding can help to reduce the amount of heat generated during welding, which can lead to better weld quality.

Another way to optimize the RSW process for dissimilar metals with different surface roughnesses is to use a filler metal. A filler metal is a soft metal that is placed between the two workpieces before welding. The filler metal will melt during welding and form a bridge between the two metals. This can help to improve the weld quality and reduce the risk of overheating. However, there are still significant gaps that need to be addressed, including comprehensive studies, standardization of surface characterization methods [35], Understanding the strength of the joint has been done by researchers, they conducted parameter research by testing the shear tensile strength, It is very important to optimize welding parameters, in order to obtain optimal joints [7], and environmental impact considerations. Addressing these challenges will lead to better weld joint quality, enhanced joint performance, and more sustainable DMRSW practices in various industrial applications. All this suggests that it is advisable to conduct a study of the roughness of the surface. Surface roughness in dissimilar material resistance spot welding plays a crucial role in determining joint quality and mechanical performance.

Based on the literature described earlier, no one has focused on research on the preparation of materials with surface roughness treatment to be welded. Therefore, research aimed at this development to solve this problem, it is necessary to optimize the parameters of resistance spot welding, with roughness treatment in the joints of dissimilar metal mild steel with stainless steel. Optimization of such parameters involves setting parameters such as current, pressure, and time to produce strong joints and minimize defects and cracks. Meanwhile, the roughness treatment dissimilar metal joints of mild steel with stainless steel is carried out to improve the mechanical properties and strength of the joints. This treatment involves the use of sandpaper so that roughness variations are obtained to remove oxides and other contaminants on the metal surface and increase the roughness of the metal surface. It is very important to conduct Dissimilar Resistance Spot Welding research to obtain a quality joint, by looking for the best parameter in the form of surface roughness of the joint. it is hoped that it can increase the strength and durability of these metal joints, so as to produce more quality and durable products. So that the manufacturing process in the industry can be more flexible with quality connections.

3. The aim and objectives of the study

The aim of the study is identifying the effect of resistance spot welding parameters on weld quality.

To achieve this aim, the following objectives are accomplished:

– to identifying the best modes the effect of surface roughness on nugget diameter;

– to identifying the best modes the effect of surface roughness on weld's mechanical properties of shear tensile;

– to identifying regularities in the formation of properties microstructure of SEM minimum and optimum mechanical properties of shear tensile;

– to identifying regularities in the formation of properties microstructure of EDS minimum and optimum mechanical properties of shear tensile.

4. Material and method

Object of research is weld quality.

The main hypothesis of the study is possibility to improve the quality and reliability of dissimilar metal welds by optimizing the resistance spot welding process for different surface roughnesses. The main hypothesis by investigating the effect of surface roughness on the nugget formation, microstructure, and mechanical properties of dissimilar metal welds. The study developed new welding procedures and machines that are optimized for welding dissimilar metals with different surface roughnesses. The surface roughness of the workpieces is the only factor that affects the quality and reliability of dissimilar metal welds. This is a simplification, as other factors, such as the welding parameters, the material composition of the workpieces, and the presence of impurities, can also affect the weld quality. The resistance spot welding process can be perfectly optimized for different surface roughnesses. This is another simplification, as there may be practical limitations to optimizing the welding process. The results of the study can be generalized to all dissimilar metal welds. This may not be the case, as the results may depend on the specific material combinations and welding conditions used in the study.

The study may assume that the welding parameters are constant for all surface roughnesses. This is not always the case, as the welding parameters may need to be adjusted to compensate for different surface roughnesses. The study may assume that the material composition of the workpieces is uniform. This is not always the case, as there may be variations in the material composition within the workpieces. The study may assume that the workpieces are free of impurities. This is not always the case, as impurities may be present on the surface or within the workpieces.

Chemical composition tests for MS and SS materials have been carried out using an optical emission spectrometer (OES), and the results are shown in Table 1. Before welding, both materials were cleaned using acetone to remove any remaining dirt or dust on the plate surface.

Table 1

Chemical composition (wt %) of: A mild steel and B stainless steel

Specimens	C	Si	Mn	Cr	S	P	Ni	Fe	Mo
MS	0.004	0	0.134	0	0.0010	0.019	0	99.5	0
SS	0.053	0.533	1.05	19.0	<0.0005	0.02	7.84	71.0	0.001

Material preparation process by cutting samples using AWS D8.9-2002 Sq-100 machine metallographic samples. The material size is 1 mm thick, 25.4 mm wide, and 100 mm long. Based on the ASTM D1002 standard shown in Fig. 1. The material preparation process with variations in roughness uses a sanding machine with variations in sandpaper numbers 60, 360, 600 and sanding patches. Furthermore, the material that has been amplified is measured for roughness using the Mitutoyo profilometer SJ 350 roughness testing machine with roughness results of 0.2, 0.3, 0.4 and 0.5 µm. Surface roughness variation treatment based on research [36].

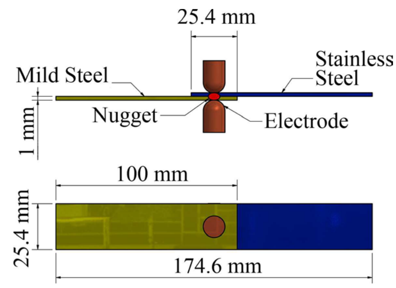

Fig. 1. Dimensions of the specimen for testing: *a* – front view of specimen on resistance spot welding; *b* – top view of specimen at resistance spot welding

The resistance spot welding machine used with a capacity of 120 kVa, the electrodes used are cone-shaped with a contact diameter of 6 mm. Flow control is analogous to ranges of 1–8 kA. Control time digitally with ranges of 1–9 seconds. Pneumatic pressure control with ranges of 10–60 psi. welding parameters such as current, welding time, and electrode force settings selected based on AWS C1.1-MC.1:2012 standard. Design and processing of experimental data using the Taguchi method based on experimental matrix L 42, Table 2. 16 experiments were conducted three times per parameter setting with a total of 48 specimens. Setting parameters *As* shown in Table 2.

Table 2

Parameter process of RSW

Levels	Welding current (kA)	Welding time (second)	Pressure Electrode (Psi)	Surface Roughness (µm)
1	5	6	20	0.2±0.04
2	6	7	30	0.3±0.05
3	7	8	40	0.4±0.05
4	8	9	50	0.5±0.04

Selection of optimum conditions larger is batter using minitab software, with the following equation [37]. To determine the influence of surface roughness parameters using the statistical method analysis of variance (ANOVA) [14]. The welding joint used is resistance spot welding Specimens were prepared for tests (shear load and SEM EDS) with different dimensions. The dimensions of the specimen for the shear load test are shown in Fig. 1, with a length of 100 mm and a width of 25.4 mm. Meanwhile, the specimen dimensions are 30 mm long and 25 mm wide for SEM EDS. Each test specimen was replicated three time.

5. Results of experiment the weld quality of dissimilar material mild steel with stainless steel resistance spot welding

5. 1. Result of the effect of welding parameters on nugget diameter

The results of the analysis of the quality of the diameter of the nugget using the Taguchi method of SN ratio is larger is better shown in Fig. 2.

Based on the results of measuring the diameter of the nugget against four response parameters, namely welding current, welding time, electrode pressure, and surface roughness. Fig. 3 it can be seen that for welding currents the minimum condition is 5 kA and the optimum condition is 8 kA. For welding time, the minimum condition is 6 seconds, and the optimal condition is 7 seconds. For minimum conditions electrode pressure at 50 psi and optimum conditions at 40 psi. For rough treatment with sanding minimum condition 0.2 μm and maximum condition 0.5 μm.

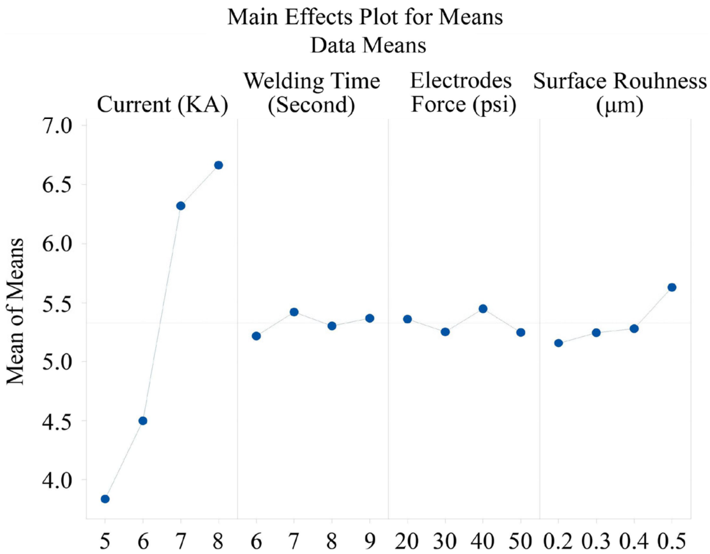

Fig. 2. Taguchi resistance spot welding nugget diameter

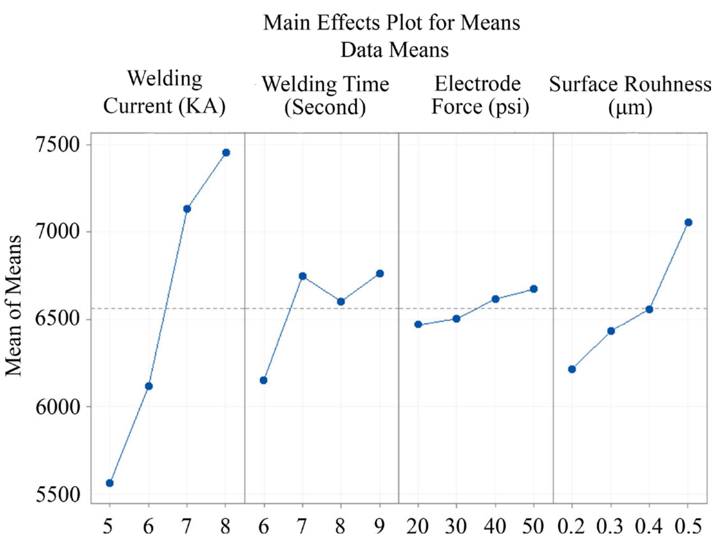

Fig. 3. Taguchi shear tensile strength

5. 2. Result the effect of welding parameters on weld's mechanical properties of shear tensile

The results of quality analysis by measuring the tensile strength of each joint with the selection of optimal conditions. The Taguchi method of SN ratio is larger is better, shown in Fig. 3.

Based on the results of the shear tensile test against four response parameters, namely welding current, welding time, electrode pressure and surface roughness. In Fig. 3 it can be seen that for welding currents the minimum condition is 5 kA and the optimum condition is 8 kA. For welding time the minimum condition is 9 seconds and the optimum condition is at 7 seconds. For minimum condition electrode pressure at 30 psi and optimum condition at 40 psi. For roughness treatment with sanding minimum condition 0.2 μm and maximum condition 0.5 μm.

5. 3. Result of minimum and optimum mechanical properties in the microstructure of scanning electron microscopy (SEM)

Specimens with the lowest and highest tensile test results are cut crosswise by joint areas, then morphological analysis with SEM. Fig. 4, *a* shows the results of SEM joints with roughness treatment of 0.2±0.04 μm have the lowest tensile strength. This happens because between mild steel joints and nuggets there are many layers of dirt (2) With a radius of 7.06 μm, this causes low shear tensile strength. The dirt layer appears because at the time of material preparation, the surface roughness is higher so that the area that is fed with heat is smaller, causing a small heat input so that the dirty layer is trapped between the nugget area and the mild steel area. The thickness of the dirt layer has a significant influence on the weldability of mild steel [38]. During welding, liquid impurities easily infiltrate the grain limits of the mild steel surface [39]. The SEM result of the connection with the roughness treatment (0.2±0.04 μm) has the highest tensile strength.

Fig. 4, *c* shows defects in lowest shear tensile strength. With rough treatment, it is able to clean the cause of the defect. Slag inclusions are nonmetallic solid materials trapped in the weld metal or between the weld metal and the base metal. The cause of this defect is slag left in the previous layer, the defect can reduce the quality of the joint, therefore with roughness treatment, the slag layer can be removed before the welding process is carried out.

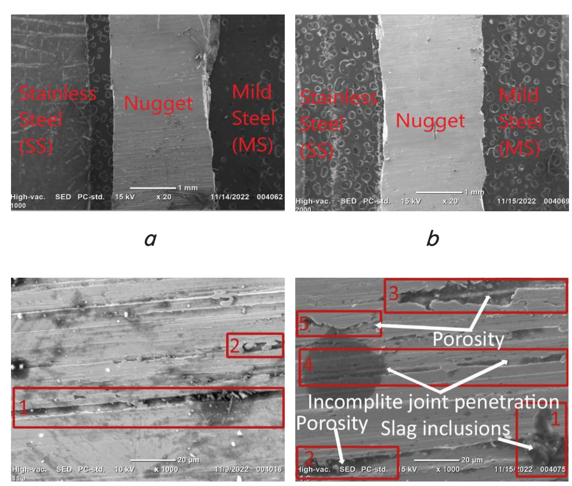

Fig. 4. SEM energy dispersive spectrometer (EDS) test results: *a* — lowest shear tensile strength; *b* — highest shear tensile strength; *c* — defects in lowest shear tensile strength; *d* — defects in highest shear tensile strength

Incomplete joint penetration. Incomplete joint penetration is the penetration of a joint that is indirectly less than the thickness of the welded joint. The cause of such defects is due to the high surface roughness so that the welding electric current is too low. Therefore, the selection of the most optimal surface roughness must be chosen properly. In addition to roughness affecting the flow of electricity, the conductivity of the material is also very influential where during the flow of electric current between the electrodes (due to the very different electrical conductivity of the material used), the highest concentration of joule heat occurs in the center of the steel sheet. If the temperature exceeds the melting point of steel, then a certain amount of molten metal is formed in the form of nugget [20].

Fig. 4, *d* shows defects in highest shear tensile strength the SEM result of the connection with the highest roughness (0.5±0.04 µm) seen in Fig. 7 has only two areas of defect. In Fig. 4, *c* there are five areas marked in red are defective areas that cause a decrease in connection quality. Unlike the Fig. 4, *d* specimens with the highest tensile strength, only two red-marked areas are visible which are defective joint areas. Specimens with the highest shear tensile strength have few defects. This is in line with researchers [40], where cracking defects are very slight at the joints with the maximum shear tensile stress.

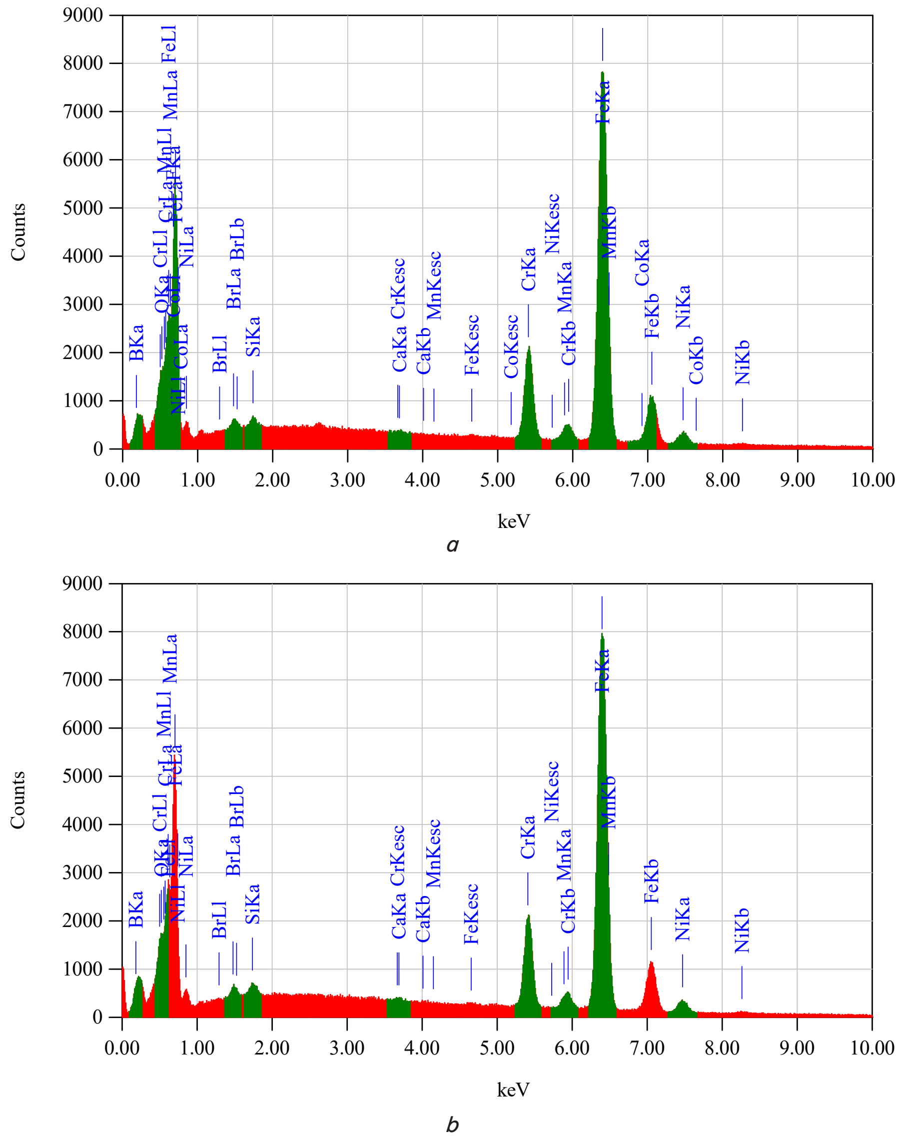

Fig. 5. EDS energy dispersive spectrometer (EDS) test results: *a* — lowest shear tensile strength; *b* — highest shear tensile strength

5. 4. Result of minimum and optimum mechanical properties in the microstructure of energy dispersive spectrometer (EDS)

The elemental content of the material that has the lowest shear tensile joints is analyzed with EDS. The composition of the selected joint of the joint surface is determined using an energy dispersive spectrometer (EDS) [41].

Based on the EDS test results for the lowest and highest joints, the material composition can be seen as follows; Fig. 5 can be seen that the highest content starts from iron (Fe) as much as 56.26 %, boron content (B) as much as 2.64 %, bromine content (Br) as much as 0.84 %, manganese content (Mn) as much as 0.78 %, calcium content (Ca) as much as 0.13 %, silicon content (Si) as much as 0.15 %, Chromium (Cr) 9.20 %, Nikel (Ni) 2.60 %, Oxygen (O) 27.39 %. Fig. 4, *b* the results of EDS analysis, it can be seen that the highest content starts from iron (Fe) as much as 56.04 %, boron (B) content as much as 2.86 %, bromine (Br) content as much as 0.73 %, fluorine content (F) as much as 0.12 %, manganese (Mn) content as much as 0.80 %, calcium (Ca) content as much as 0.07 %, silicon (Si) content as much as 0.19 %, Chromium (Cr) 9.25 %, Nikel (Ni) 2.62 %, Oxygen (O) 27.47 % EDS stands for spectral dispersive energy [39].

6. Discussion of the effect of surface roughness on nugget diameters, tensile strength, microstructure scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS)

Surface roughness has been shown to have a significant effect on the nugget diameter, tensile strength, microstructure, and elemental distribution in resistance spot welds. As shown in Fig. 2 surface roughness is very influential to increase the diameter of the nugget, where at 0.5 µm roughness produces the largest nugget dimater. This happens because surface roughness will limit the contact area when the two sheets are joined together. As a result, when current is passed through the sheet, electrons will be forced to flow through the narrow area where the surfaces come into contact. According to researchers [42] severe frictional conditions make micrometallurgical processes form atom-crystals, resulting in modified layers with unique tribological characteristics forming on the surface. This is because the increased surface area provides more sites for the initiation and growth of weld nuggets.

Surface roughness is very influential to increase shear tensile strength because, As shown in Fig. 3 surface roughness is very influential to increase shear tensile strength, where at 0.5 μm produces the largest shear tensile strength. As a result, when current is passed through the sheet, electrons will be forced to flow through the narrow area where the surfaces touch. This creates local extremes in current density that lead to increased resistance. Resistance causes heat that melts the welding area. The effect of surface roughness on tensile strength is more complex. Some studies have shown that increasing surface roughness can increase tensile strength, while others have shown no effect or even a decrease in tensile strength [43]. The effect of surface roughness on tensile strength is likely dependent on a number of factors, such as the welding material, welding parameters, and loading conditions.

As shown in Fig. 4 the SEM result highest tensile strength this happens because the surface roughness in the joint area is able to affect electrical resistance where the lower the surface roughness of the connection, the higher the heat supply so that it can push the Chromium (Cr) layer in the nugget area resulting in an increased connection. Fig. 4, *b*, the Chromium (Cr) layer is smaller at *R* 1.56 μm. This phenomenon is similar to research that has been studied researcher [44], they concluded that it is imperative that the zinc coating is squeezed out of the molten metal zone before melting, in order for welding quality to improve. Surface roughness can also affect the microstructure of resistance spot welds. Increasing surface roughness can lead to a finer grain structure in the weld nugget. This is because the increased surface area provides more sites for nucleation of grains. The temperature gradient between the two specimens is dissimilar, causing the maximum temperature to exceed the melting point of the two materials where the first melts the zinc layer (420 °C should be inserted by the symbol) then the inner layer (950 °C) and the mild steel joint (1450 °C). The interface part of the mild steel/stainless steel sheet melts the melting range of the Chromium (Cr) material which affects the strength of the weld joint, where less Chromium (Cr) is trapped, causing the joint strength to increase. From the resulting weld ties, it is important to know the structure of the transition zone and adjacent areas [14].

EDS can be used to determine the elemental composition of resistance spot welds. EDS can be used to identify the presence of alloying elements and other impurities in the weld. As shown in Fig. 5 result of EDS there is of high amounts of manganese (Mn) in these particles is an indication that these particles are very likely to be defective hole inclusions [25, 26]. It is possible to see the EDS analysis of the shear tensile test joints that have the lowest shear tensile strength and the highest shear tensile strength, dissimilar joints mild and stainless steel, according to the ratio of weight and atomic ratio of mild and nickel elements.

One of the limitations of this research is that data collections on the variations surface roughness at higher roughness by using coarser sandpaper but requires a roughness measuring instrument capable of measuring high roughness. For the development of future research, roughness treatment can be tested on other dissimilar materials such as mild steel with galvanized steel. With a focus on rudeness treatment.

7. Conclusions

1. The surface roughness that most affects the size of the nugget diameter is a roughness value of 0.5 μm.
2. The surface roughness that most affects the tensile strength is a roughness value of 0.5 μm.
3. SEM serves as a valuable tool for examining the microstructure of resistance spot welds. SEM images enable the measurement of nugget diameter, grain size, and other microstructural features. SEM test results for welded joints that have the lowest shear tensile strength, have defects in the form of slag inclusion and incomplete penetration.

While SEM test results for the mechanical properties of welded joints from the highest shear tensile test specimen, have less dirt gap between mild steel and stainless steel, with two defective areas. Welding defects degrade the quality of welded joints, therefore with surface roughness treatment, it is able to reduce defects, thereby improving the quality of welded joints.

4. EDS facilitates the determination of elemental composition within resistance spot welds. It identifies the presence of alloying elements and impurities in the weld. EDS test results for mechanical properties of welded joints, from the lowest shear tensile test result specimens, Have less silicon (Si), Chromium (Cr) and Nickel (Ni) content. While EDS test results for mechanical properties, welded joints of the highest shear tensile test specimens, have more silicon (Si), Chromium (Cr) and Nickel (Ni).

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

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